Renewable and Sustainable Energy Reviews 39 (2014) 79–86

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Optimal distributed generation planning at a local level – A review of Serbian renewable energy development

Ilija Batas Bjelic [a,*], Rade M. Ciric [b]

[a] University of Belgrade, School of Electrical Engineering, Bulevar kralja Aleksandra 73, 11120 Belgrade, Serbia
[b] Higher Education Technical School of Professional Studies, Novi Sad, Skolska 1, Serbia

ARTICLE INFO

Article history:
Received 26 March 2014
Received in revised form
29 May 2014
Accepted 7 July 2014
Available online 27 July 2014

Keywords:
Distributed generation
Microgrid
CO_2 reductions
Decentralized energy planning

ABSTRACT

With the Law on Energy and its acceptance by the Covenant of Mayors, local authorities in Serbia are obliged to prepare action plans for the development of distributed generation and energy efficiency measures aiming at reducing CO_2 emissions. The development of distributed generation (wind, photovoltaic, hydro and combined heat and power plant) is an asset to the local authorities wishing to become energy independent microgrids that could relieve the national transmission grid in the way of reducing amount of electricity to be transported from centralized generation to the end-user. Using the simulation tool HOMER, an optimal configuration plan of the municipal microgrids for Serbia has been drawn, in order to obtain the lowest total net present costs during the planning period under various levels of CO_2 reduction constraint. The increase of the end-user specific costs for energy has been quantified in a sensitivity analysis based on this constraint in the local authority microgrid.

Contents

1. Introduction

Local authorities in Serbia are obliged by the Law on Energy to prepare action plans for the development of distributed generation and energy efficiency measures aiming at reducing CO_2 emissions. The development of distributed generation (wind, photovoltaic, hydro and combined heat and power plant) is an asset to the local authorities wishing to develope energy independent microgrids

Abbreviations: CHP, Combined heat and power; PV, Photovoltaic; NPC, Net present costs; NPV, Net present value; O&M, Operation and maintenance

* Corresponding author. Tel.: +381 11 3370 165; fax: +381 11 3248 681.
E-mail addresses: ilija.batas@gmail.com, batas@etf.rs (I. Batas Bjelic), rciric@aol.com (R.M. Ciric).

http://dx.doi.org/10.1016/j.rser.2014.07.088
1364-0321/

that could relieve the national transmission grid in the way of reducing amount of electricity to be transported from centralized generation to the end-user.

This research has been performed to assist local authorities in Serbia to develop microgrids that reduce the CO_2 emission at minimal abatement costs. Although technically developed and welcomed by national and EU legislative and politically accepted by local authorities, the microgrids are far from the realization, stuck at the first step – planning. Without a clearer economic prospective of different micro-grid configuration options in a decentralized planning approach, good investment decisions could not be made. Alternative configuration options should be explored and clearly sorted by their environmental and economics effects. Such options should be presented in detail according to the clearly defined sustainable partnership programs. The purpose of this research is to develop a methodology for minimal CO_2 abatement cost microgrid planning at the local level.

The microgrid on a given voltage level (AC and/or DC) is a whole consisted of distributed generation, energy storage, different end-user categories and appropriate infrastructure [1–3]. The microgrid is part of a smart grid that assumes a municipality and distribution level, with a chosen electricity supplier at the transmission level. The microgrid concept is different from the traditional distribution grid in the way that it is an autonomous and controllable entity that works independently or connected within a national energy system wide smart grid [1]. Thus the municipal microgrid could be connected to the transmission network and with or without generation based on fossil fuel energy sources [4]. Distributed generation enables a municipal level microgrid to be autonomous [5,6], to increase its reliability [7], and robustness [8] and unburden the transmission grid [1,3]. The operation of distributed generation could decrease local authorities peak demands to the transmission grid and associated capacity payments [1].

Besides its benefits, the operation of microgrids has been followed by issues [9], e.g. island mode operation [7], fault detection [10], etc. Those issues could be detected in the current pilot microgrid projects that are developed worldwide [2], in the U.S. [9], Europe [7], Iran [8], but also in FYR Macedonia [11] and Hungary [12]. It is difficult to quantify the bounds of the microgrid term [13] because the focus is not on the size but on its localization [14] and on the level of autonomous operation to the transmission grid.

A review of Serbian energy policy has been done in [15], but without a conclusion about how this should be implemented at the local level. According to Serbian Energy Law from 2011 [16], autonomous provinces and local authorities are obliged to include energy demand in their development planning, as well as terms of securing sufficient energy capacities in accordance to [17] current Energy strategy of Serbia and the action plan until 2015 [18]. To increase the usage of renewable energy sources, National Renewable Energy Action Plan (NREAP) will be realized through the development of distributed network for smaller distributed generation [19]. According to the law, the jurisdiction of the local authorities are small distributed generators and storage until 1 MW, especially in the heating sector where decentralized planning is more welcomed through the communal activity. Therefore municipalities in Serbia are responsible for their energy policy and free to join sustainable partnership programs accepting their binding targets and time dynamics.

Joining the mainstream European movement, Covenant of Mayors [20], local and regional authorities, are committed to increasing energy efficiency and use of renewable energy sources on their territories with a goal to reduce current CO_2 emissions for more than 20% to 2020. Committed to reduce greenhouse gas emissions at their source, proclamated in Climate Alliance [21], local authorities are accepting the goal of, 50% reductions until 2030 of their emissions from 1990, plus 10% every fifth year afterwards.

Covenant of Mayors signatories, among 5471, in 2011 and 2012, were seven Serbian local authorities: Temerin, Titel, Žabalj, Zrenjanin, Niš, Vranje and Varvarin [22]. However, they have not developed their action plans on how to meet those reduction goals and they are now “on hold”, since the deadline has passed [23]. Two new municipalities, Ivanjica and Kula signed in 2014.

Another problem for the development of renewable energy projects is the unwillingness of local authorities and citizens to tackle these problems and make energy policy decisions [24], although energy related individual consumption is not an insignificant part (17.3%) of available household budget in Serbia [25].

The decentralized planning approach has advantages over the centralized one, observing the complexity of the decision making process, investment reasons and current project realization record for Serbia [26]. Local authorities and citizen participation in smaller projects [27], based on bottom up strategy for delivering renewable energy [28], is a key for good decision making and decision viability [5], in addition to administrative procedures that are shorter comparing to the strategic decisions on the national level. Investment reasons in line to the decentralized approach have higher availability of smaller credit lines [29], in comparison to big projects that can be financed only by leading world financial institutions in a highly competitive environment.

Current project realization record of renewable energy project has been under 2 MW per project. In Germany, 50% of the realized renewable projects are owned by individuals and 97% in solar photovoltaic [30].

Decentralized planning is needed for the full separation of the state-owned generation company into generation, transmission, and distribution entities. According to the Energy Law amendments, the wholesale competition and third party access, have been scheduled for mid 2014 in Serbia [16]. The third party access to the distribution level should be done first, particularly when there are payment problems [31]. The decentralized planning at regional and local authorities levels [32–36], is desirable since it postpones investment in the grid infrastructure through the rethinking of supply options [5,37] and saves distribution losses [38]. The decentralized planning has been achieved so far in Europe (Italy, Slovenia, Austria and Germany, etc), the U.S. [5,6], and in Japan , [10]as well as has practiced in developing countries. Typically the method of linear programming under constraints has been used for sizing and configuration of the decentralized generation [4,39]. Mostly, the usage of fossil fuels [40] or levelized costs of electricity have been minimized [41,42].

HOMER [43] is a widely used [44] and free DG planning simulation tool, which gives priority to a variable renewable energy source in dispatch, taking into account the operating reserve [43,44]. This tool considers different investment alternatives in electricity and heat generation and moderation (transport demand is not included) in order to meet the given yearly demand at minute to hour level. HOMER helps in feasibility assessments and significantly simplifies profitability assessment of a microgrid from the view of the local authority [14].

The optimization goal is the minimization of total (investment and operative) net present costs on the project lifetime, discounted to the present. This is a combinatorial search optimization problem, which can be solved by heuristics of genetic algorithm [45]. Decision variables of the model could be the size and number of generators, moderators (batteries and other storage) and converters of the microgrid.

Constraints in the model are technical, economical and regulatory, e.g. the emission cap or share of renewable energy sources in the gross final electricity consumption [46]. After the simulation and optimization, HOMER tool can be used for the sensitivity analysis to every input variable or constraint. For the sensitivity analysis, multiple simulations based on different values for each variable within the model were performed.

HOMER tool has been used for optimal planning of a microgrid [4,8,46], grid parity assessment of photovoltaic (PV) – battery microgrid in the U.S. [47], also for the sensitivity analysis to input variables, average wind speed and storage size, in Canada [48]. Besides, it was applied to input variables, fuel price and wind parameters, CO_2 tax and regulatory constraints, as well as the share of a renewable energy source in electricity production [49,50]. In the article [51], humanitarian, technical and economic benefits of solar PV systems are proven for a remoted hospital microgrid. The cost effectiveness of the isolated grid in rural electrification solutions based on hybrid renewable energy system in Serbia and in Malaysia has been shown [37,52].

In this article, the sensitivity analysis of energy costs against the regulatory CO_2 emission reduction constraints for microgrids is performed. In comparison to buying the electricity from a national mix of transmission grids, CO_2 emission reductions are achieved by developing the distributed generation by local-authority optimal investment planning. Reductions are based on supply side measures, not on the end-user energy efficiency neither the transport sector. The optimal equipment consideration for optimal sizing and configuration of a local authority microgrid has been based on the minimization of total NPC under constraints.

The main contribution of the proposed planning approach is that it gives clear economic and environmental merits of the microgrid configurations that are feasible for sustainable partnership programs, and which are needed for investment decisions.

2. Method

Using the HOMER tool, the simulation, optimization and sensitivity analysis for the local authorities, subject to the regulatory CO_2 emission reduction constraint (see Table 1) are carried out. The local authority microgrid model is based on the historical values of energy consumption, efficiencies, fuel emission factors and heat values, as well as on component prices as input variables [43].

2.1. Scenario development

To see how levelized costs of energy increase with the sustainable local authority microgrid development under CO_2 constraints, two scenarios were compared:

- **Base scenario** assuming that the local authority electricity load (Primary Load 1) has been met through the transmission grid and Thermal Load of the natural gas fired boiler.
- **Microgrid development scenario** with addition of distributed generation plants e.g. micro CHP, Hydro, wind (Vestas V82) and solar PV.

Table 1
Emission reduction levels and total emissions in developed microgrid scenario.

Reduction CO_2 [%]	*Total emission CO_2 [kg/yr]*
0 (Base scenario)	32,101,560
10	28,891,404
20	25,681,248
30	22,471,092
40	19,260,936
50	16,050,780
60	12,840,624
70	9,630,468
80	6,420,312
90	3,210,156
97	963,047

2.2. Economic modeling

Economics play an integral role both in HOMER's simulation process, wherein it operates the system so as to minimize total NPC, arbitrarily given preference over NPV metrics by HOMER developers, and in its optimization process, wherein it searches for the system configuration with the lowest total NPC [53]. The total NPC condenses all the costs and revenues that occur within the project lifetime into one lump sum in today's Euros (€), with future cash flows discounted back to the present using the discount rate [53]. HOMER uses Eq. (1) to calculate the total NPC:

$$C_{NPC} = C_{ann,\ tot}/CRF(i,\ R_{proj}) \tag{1}$$

where $C_{ann,tot}$ is the total annualized cost, i is the annual real interest rate (the discount rate), R_{proj} the project lifetime, and $CRF(x)$ is the capital recovery factor, given by:

$$CRF(i, N) = i(1+i)^N/((1+i)^N - 1) \tag{2}$$

where N is the number of project lifetime years.

The total NPC of a microgrid system is the present value of all the costs that it incurs over its lifetime, minus the present value of all the revenue that it earns over its lifetime. The total NPC includes the costs of initial construction, component replacements, maintenance, fuel, plus the cost of buying power from the grid, and miscellaneous costs such as penalties resulting from pollutant emissions. Revenues include income from selling power to the grid, plus any salvage value that occurs at the end of the project lifetime. To calculate the salvage value of each component at the end of the project lifetime, HOMER uses:

$$S = C_{rep}R_{rem}/R_{comp} \tag{3}$$

where S is the salvage value, C_{rep} is the replacement cost of the component, R_{rem} is the remaining life of the component, and R_{comp} is the lifetime of the component. The total operation and maintenance (O&M) cost of the system is the sum of the O&M costs of each system component. The grid O&M cost is equal to the annual cost of buying electricity from the grid (energy cost plus fixed demand cost) minus any income from the sale of electricity to the grid. HOMER uses Eq. (4) to calculate the levelized costs of energy:

$$COE = (C_{ann,\ tot} - c_{boiler}E_{thermal})/(E_{prim} + E_{def} + E_{grid,sales}) \tag{4}$$

where $C_{ann,tot}$ is the total annualized cost, c_{boiler} is the boiler marginal cost [€/kWh], $E_{thermal}$ is the total thermal load served [kWh/yr]. E_{prim} and E_{def} are the total amounts of primary and deferrable load, respectively, that the system serves per year [kWh/yr], and $E_{grid,sales}$ is the amount of energy sold to the grid per year [kWh/yr].

Eq. (4) is based on arbitrary decisions made by HOMER developers:

1. To isolate that portion of the total annualized cost that reflects the cost of producing electricity (as opposed to producing heat), it is decided to subtract from the total annualized cost, the product of the boiler's marginal cost and the total annual thermal load.
2. To use the amount of electric load the system actually serves, rather than the total electric demand, in calculating the total amount of useful electricity produced by the system. The two are not necessarily the same if the user allows some unmet load.
3. To include the amount of electricity sold to the grid in the total useful electrical production.

This has positive outcomes to the decentralized generation economic viability, especially CHP since heat energy production was observed. Thus, in its optimization process, HOMER ranks the system configurations according to NPC rather than levelized costs

of energy. The economic benefit for the consumer is obtained from the fact that local authority generation could be economically preferable as opposed to buying it from the grid. Moreover, the economic parameters of interest for decision-making and the mentioned sensitivity analysis are:

- Total Capital Cost, which is the sum of the initial capital costs for components at the beginning of the project, and
- return on investment [%] given by

$$ROI = (R_N - R_0)/(NR_0) \tag{5}$$

where R_0 is the revenue at the beginning of the project [€], negative by the rule, R_N is the revenue at the end of the project [€], positive by the rule, and N is the project lifetime [yr].

- The internal rate of return [%] of the proposed microgrid system is the discount rate at which the base case and current system have the same net present cost. The decision to invest should be made if the internal rate of return is higher than the annual real interest rate [54].
- The simple payback [yr] is the number of years wherein the cumulative cash flow of the difference between the current system and base case system switches from negative to positive:

$$P = (C_{inv,\ microgrid} - C_{inv,\ base})/(C_{O\&M,\ base} - C_{O\&M,\ microgrid}) \tag{6}$$

where

$C_{inv,\ microgrid}$	are microgrid investment costs [€],
$C_{inv,\ base}$	are base case investment costs [€],
$C_{O\&M,\ microgrid}$	are microgrid O&M costs [€], and
$C_{O\&M,\ base}$	are base case O&M costs [€].

By the rule, base case investment cost amounts to zero (0), and O&M are higher than in the microgrid case because of a lower amount of purchase by the transmission network.

2.3. Technical modeling

2.3.1. Electric and thermal loading

The electric load of the microgrid at the distribution level has been obtained by scaling the total Serbian national load to a maximal hourly load of 5665 kW with the load factor of 0.6 [55]. The scaling of the load has been established assuming that the total microgrid electricity consumption was of 30 GW h/yr from the transmission grid.

The heat demand of the microgrid has been obtained from the scaled heat demand of four cities in Serbia, according to the heating degree day methodology, scaled to 2500 households with 150 kWh/m^2, 80 m^2. The average daily heat demand is 65 MW h/day and the peak load is 10305 kW with the capacity factor of 0.263 [55]. Heating degree days are defined with regard to a base temperature – the outside temperature above which a building needs no heating.

2.3.2. Optimal sizing and configuration of microgrid

According to the base scenario, the thermal load has been supplied from the natural gas fired district heating boiler rated with the efficiency of 70%. The electric load has been supplied by the electricity bought from the transmission grid, holding the capacity of 10000 kW, at two scheduled rates, 2 c€/kWh (0–8 h) and 6 c€/kWh (8–24 h), without net metering, fixed costs and additional charges and constraints. With the aim of planning an optimal sustainable microgrid, the investment in the following plants has been considered in addition to the base case:

- *Micro CHP* rated to 0, 1000, 2000, and 4000 kW, with the minimum load of 30%, 60000 operating hours lifetime (20 yr around 3000 operating hours), natural gas fired with combined efficiency at 73%. The capital costs and replacement costs of the CHP plant are estimated at 0.6 €/kW and O&M cost at 0.01 €/h.
- *Hydro* rated to 0 and 2700 kW, efficiency of 75% and fifty (50) years lifetime. Capital costs of the hydro plant are assumed to 1.84 €/kW;
- *Wind* (*Vestas V82*) with 0, 1, 2, 4 and 8 units type "Vestas V82" rated to 1650 kW/unit, twenty (20) years lifetime, with an 80 m high mast and the surface roughness length of 0.25 m (many trees, few buildings). The capital costs of the wind plant are 1400 €/kW, the replacement costs amount to 900 €/kW and O&M costs of 32 €/kW per year;
- *PV plant* rated 0, 1000, 2000, 4000, 8000 and 16000 kW, 15 yr lifetime, degrading factor of 80%, fixed slope at 32°, and orientation to the South. The capital costs for the PV system (PV panels, mounting hardware, tracking system, control system, wiring and installation) are estimated to be 740 €/kW and the replacement cost to be 400 €/kW.

The optimal equipment consideration for optimal sizing and configuration of a local authority microgrid has been based on the minimization of total NPC under constraints.

2.3.3. Resource constraints

The available resources at the local level are:

- *Solar resource* with average yearly radiation of 3.47 kWh/day (1040–5770 kWh/m^2/day, December minimum, July maximum),

Table 2
System sizing, configuration and economic parameters of investment in microgrid development scenarios.

Microgrid development scenario	Hydro	CHP	PV	Vestas V82	Total capital cost	Total net present cost	Levelized costs of energy	Internal rate of return	Return on investment	Simple payback
	[MW]				[M€]		[€/kW h]	[%]		[yr]
10%	0	2	0	0	1.2	22.8	0.05	9.08	7.63	9.95
Covenant of mayors (20% reductions)	2.7	0	0	0	4.9	22.9	0.05	11.7	9.14	10.3
30%	2.7	1	0	0	5.5	23	0.051	11.4	9	10.3
40%	2.7	3	0	0	6.7	23.3	0.052	10.9	8.65	10.4
Climate Alliance (50% reductions)	2.7	4	1	0	8	23.9	0.054	10.1	7.86	11.1
60%	2.7	4	2	0	8.7	24.3	0.055	9.67	7.49	11.3
70%	2.7	4	8	0	13.2	26.5	0.063	8.26	6.03	12.2
80%	2.7	4	8	1.65	12.5	26.6	0.064	8.03	5.69	12.9
90%	2.7	3	16	0	18.5	29.2	0.073	7.38	5.01	12.8
97%	2.7	2	16	1.65	20.3	30.6	0.078	6.92	4.4	13.5

obtained from NASA [56] and in line with measurements in Serbia [57],

- *Wind resource* with average annual speed of 3.61 m/s,
- *Hydro resource* with average annual flow of 55 m^3/s and biological minimum at 1.9 m^3/s, and
- *Natural gas* supply without constraints.

2.3.4. Other constraints

The following other constraints concerned are:

- *System control*: excess electricity from the microgrid variable renewable energy sources could be used as a dump load for water heating. The microgrid system total generation could be sized less than the load since it is connected to the transmission grid;
- *Emissions*: CO_2 emission limitations are considered for the sensitivity analysis without emission penalties, while the emission trade scheme is not possible in the current situation;
- *Economics*: the project horizon is twenty five (25) years, with the annual real interest rate of 10% without fixed system capital and O&M costs, and capacity shortage penalty; and
- *Constraints*: in this case, the operating reserve is the transmission grid. It can supply enough reserve capacity for any microgrid development scenario, since it has been designed for the case without distributed generators.

2.4. Simulation, optimization and sensitivity analysis

Firstly, the total emission of the local microgrid was calculated in a simulation without emission constraints for the base scenario. A feasibility of the system is determined by the balance constraint satisfaction for each of the 8760 h during one year. During the simulation HOMER checks the balance between the electricity consumption and grid purchase and between the heat consumption and gas boiler production. For the base case configuration, costs by type have been calculated for each microgrid component, discounted and summarized over the planning period. The emission intensity of the Serbian electricity grid has been assumed to be 850 gCO_2/kWh_{el} [58,59]. It is higher than in the heat sector [60], thus CO_2 reductions should be focused on it. Main goal of the base case simulation was to calculate total yearly emissions.

For the sensitivity analysis, the emission constraints were added in the range of 0–97% reductions (*Emissions*), and the multiple simulations have been continued for various microgrid sizes and configuration for each level of the yearly emission constraint (see Table 2). During these simulations feasibility of the microgrid system was not checked only for the balance but also for the emission constraint. In total 300 feasible configurations of the municipal microgrid, out of 350 (7 PV, 5 wind, 5 micro CHP plant sizes with or without hydro power plant) were simulated 11 times for different emission constraints, counting in total 3300 simulations. In those simulations the electricity excess production or shortage are moderated thought the transmission grid. Reductions in emissions are therefore calculated corrected to the possible positive and negative balance with the transmission grid.

Each emission constraint level has optimal microgrid size and configuration with the minimal total NPC. The sensitivity analysis provides the microgrid with marginal CO_2 abatement costs. It is expected that higher emission constraints will be met through higher investment costs and levelized costs of energy. An economic comparison of each developed microgrid scenario is possible using HOMER *Table* and *Graph* comparison feature (*Simulation results* > *Compare*).

3. Results and discussion

The levelized costs of energy increase from 0.048845 to 0.078152 €/kWh for the local authority microgrid, based on CO_2 emission constraints, have been quantified in the sensitivity analysis in Fig. 1. For the lower half reduction constraints (10–50%), slower increase in the levelized costs of energy has been observed for 10%. However it develops faster for emission constraints in the higher half (50–97%) amounting to 45%.

The development of a microgrid configuration under CO_2 emission constraint can be tracked in Fig. 2. This figure shows plant types and sizes chosen to have the minimal total NPC for the certain CO_2 emissions reduction scenario.

The base case CO_2 emissions of 32101560 kg/yr could be reduced by 10% by:

- adding the micro CHP plant of 2000 kW, and
- increasing consumption of 1654597 m^3 natural gas in comparison to the base scenario.

A 20%-reduction in emissions could be achieved by:

- adding the hydro power plant.

A reduction of 30% has been achieved by:

- adding the hydro power plant, and
- adding the micro CHP of 1000 kW.

A reduction of 40% has been achieved by:

- adding the hydro power plant and
- adding the micro CHP of 3000 kW.

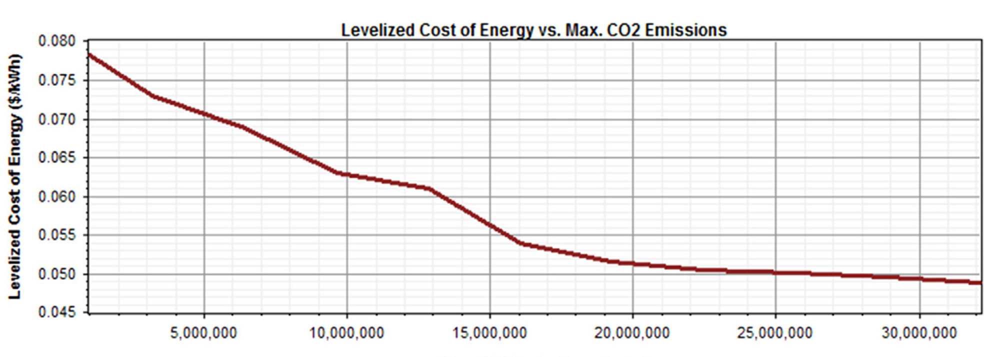

Fig. 1. Levelized cost of energy sensitivity analysis under CO_2 emission constraints in developed microgrid scenario.

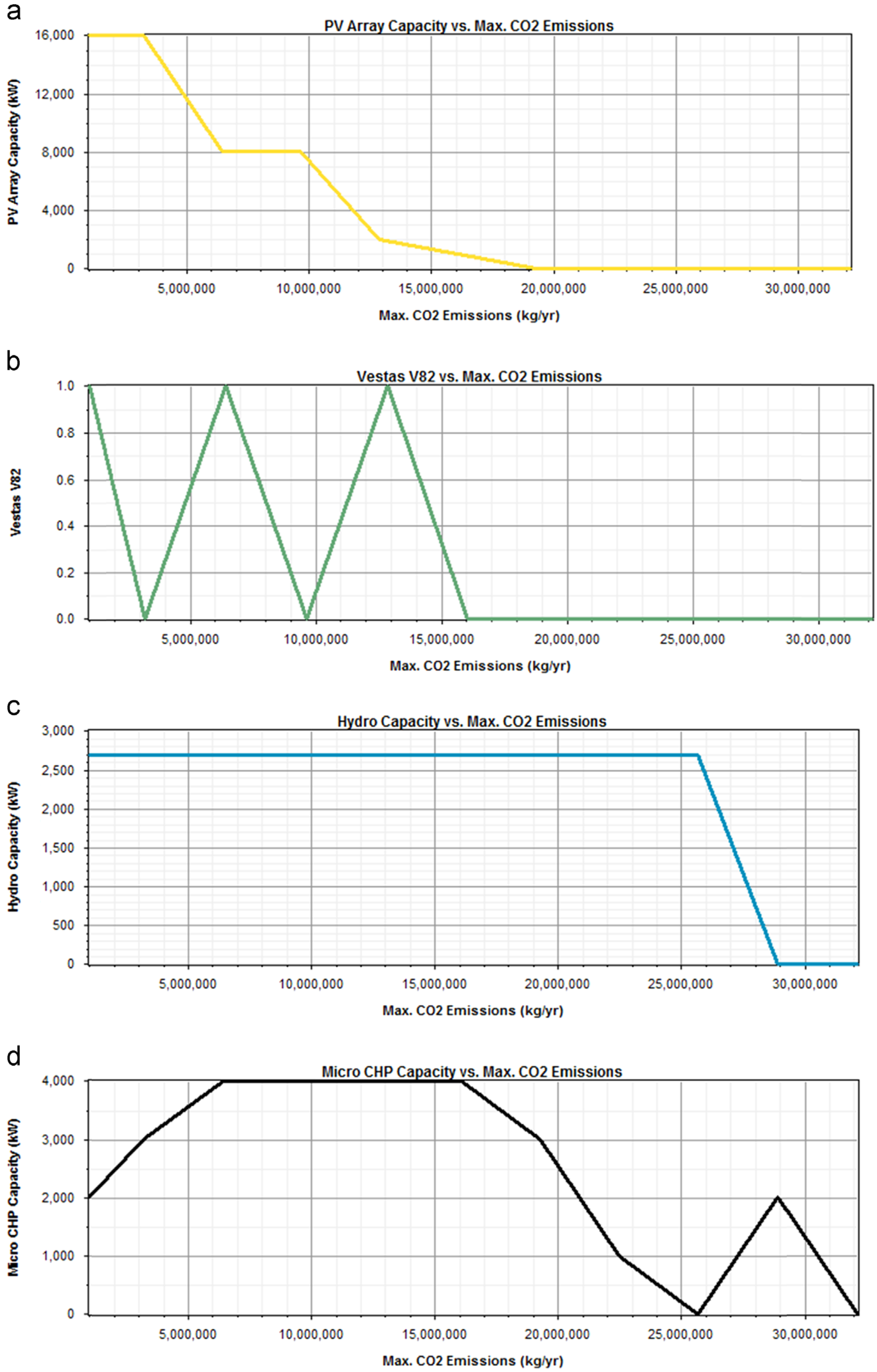

Fig. 2. Microgrid distributed generation development scenarios: (a) photovoltaic, (b) wind power, (c) hydro power and (d) combined heat and power plant.

Further emission reductions of 50%, accepted by the Climate Alliance, have been achieved by:

- adding the hydro power plant,
- adding the PV plant of 1000 kW, and
- adding the CHP plant of 4000 kW.

60% of emission reductions have been achieved by:

- adding the hydro power plant,
- adding the PV plant of 2000 kW, and
- adding the CHP plant of 4000 kW.

70% of emission reductions have been achieved by:

- adding the hydro power plant,
- adding the PV plant of 8000 kW, and
- adding the CHP plant of 4000 kW.

An even higher emission reduction (80%) has been achieved by:

- adding the hydro power plant,
- adding the PV plant of 8000 kW,
- adding the CHP plant of 4000 kW, and
- adding the wind power plant of 1.65 MW.

Very high emission reductions (90%) have been achieved by:

- adding the hydro power plant,
- adding the PV plant of 16,000 kW, and
- adding the CHP plant of 3000 kW.

A significant emission reduction up to 97% could be achieved by:

- adding the hydro power plant,
- adding the PV plant of 16000 kW,
- adding the CHP plant of 2000 kW, and
- adding the wind power plant of 1.65 MW.

The marginal CO_2 abatement cost for the local authority accepting the Covenant of Mayors agreement (the building of a hydro power plant) amounts to 4.9 M€ and around 8 M€ (building of a hydro power, CHP, and PV plants) if they join the Climate Alliance. Levelized costs for energy on the project horizon stand for 0.050157 €/kWh and 0.053807 €/kWh. Although the scenario with lower marginal abatement costs in the case of Convent of Mayors is possible (e.g. 3 M€, CHP of 4000 kW and PV plant of 1000 kW), the levelized costs for energy in this scenario are higher (0.052 €/kWh).

The economic parameters for investments in the **developed microgrid scenario** – return on investment, internal rate of return, in percent, and simple payback in years, are given in Table 2 for each level of CO_2 reduction constraint and for both sustainable partnership programs – The Convenant of Mayors and Climate Alliance. Those parameters are given in comparison with the **base scenario**. The return on investment is at its highest with the hydro power plant (11.7%) and at its lowest with the highly CO_2 constrained microgrid (6.92%).

Both sustainable partnership programs have proven to be profitable while the internal rate of return is higher than the annual real interest rate. The simple payback time for investments in local authority microgrids ranges from 10 to 13.5 yr, without considering any financial support mechanism for renewable energy e.g. feed in tariff.

4. Conclusions

In this article, a decentralized planning approach for the optimal development of a microgrid for six local authorities in Serbia, has been proposed. However, these projects stopped at the first step and are now far from the realization of their renewable energy policies. The proposed planning approach shows clear economic and environmental merits of the microgrid configurations that are feasible for sustainable partnership programs e.g. Convenant of Mayors, and which are needed for investment decisions. The importance of such investment decisions is even higher since political and technical obstacles in Serbia are removed. The sustainable partnership programs could trigger the energy transition in Serbia from the bottom up.

The proposed simulation model is suitable for CO_2 abatement cost allocation in small local authorities (Temerin, Varvarin, Žabalj, Titel, Ivanjica and Kula) without significant CO_2 emitting industries and transport, or the marginal CO_2 abatement costs are assumed to be higher than in the electricity production sector. For every local authority the minimal net present costs of the microgrid development for the satisfaction of a given CO_2 emission constraint, can be calculated and presented in detail based on its size and configuration.

The analysis has shown that natural gas micro CHP is the optimal solution for both sustainable partnership programs, while they both have been focused only on CO_2 reductions, and not the increased share of renewable energy sources for instance. The hydro power plant has been a renewable solution of the first choice, where available. The CHP solution is less favorable when it comes to the higher (over 50%) CO_2 reduction constraints, where marginal abatement costs in electricity production grow faster and renewable energy sources should be used significantly.

Besides hydro units, solar photovoltaic plants show a constant increase in usage for the higher CO_2 reductions, while wind units are occasionally chosen (one turbine or none). This conclusion is based on temporal and local assumptions and could be different for other case studies.

Financial measures for the increased use of renewable energy sources should include special funding in order to ensure public benefit and development (employment, trade) at a local level, and CO_2 reduction as a public benefit at national level.

The proposed decentralized planning approach can be applied in other countries and for different sustainable partnership programs of the local authorities.

Acknowledgments

This work is part of the Research Project "*Integrated Energy Networks*" no. III 42009/2011, supported by the Ministry of Education and Science of the Republic of Serbia (Grant no. III 42009/2011).

Solar data were obtained from the NASA Langley Research Center Atmospheric Science Data Center Surface Meteorological and Solar Energy (SSE) web portal, supported by the NASA LaRC POWER Project.

Authors are thankful to the Marianne Curguz, Nicolas Batas Bjelic, Nenad Radosevic and Branka Petrovic for English proof reading of the article, and anonymous reviewers for valuable comments.

References

[1] Mijailović V. Distribuirani izvori energije: principi rada i eksploatacioni aspekti – in Serbian language. Beograd: Akademska misao; 2011.
[2] Lidula NWA, Rajapakse AD. Microgrids research: a review of experimental microgrids and test systems. Renew Sustain Energy Rev 2011;15:186–202.
[3] Chowdhury S, Crossley P. Microgrids and Active Distribution Networks: Institution of Engineering and Technology 2009.
[4] Hafez O, Bhattacharya K. Optimal planning and design of a renewable energy based supply system for microgrids. Renew Energy 2012;45:7–15.
[5] Müller MO, Stämpfli A, Dold U, Hammer T. Energy autarky: a conceptual framework for sustainable regional development. Energy Policy 2011;39:5800–10.
[6] Schmidt J, Schönhart M, Biberacher M, Guggenberger T, Hausl S, Kalt G, et al. Regional energy autarky: potentials, costs and consequences for an Austrian region. Energy Policy 2012;47:211–21.
[7] Kroposki B, Lasseter R, Ise T, Morozumi S, Papatlianassiou S, Hatziargyriou N. Making microgrids work. IEEE Power Energy Mag 2008;6:40–53.
[8] Bahramara S, Jafari F, Rahimi-Kian A, Lesani H. Planning of a grid-connected smart micro-power system. innovative smart grid technologies – Asia (ISGT Asia). IEEE 2012:1–5 (2012).

[9] Lasseter RH. Microgrids and distributed generation. J Energy Eng 2007;133: 144–9.
[10] Jiayi H, Chuanwen J, Rong X. A review on distributed energy resources and MicroGrid. Renew Sustain Energy Rev 2008;12:2472–83.
[11] Krkoleva A, Taseska V, Markovska N, Taleski R, Borozan V. Microgrids: the agria test location. Thermal Sci 2010;14:747–58.
[12] Morais H, Kádár P, Faria P, Vale ZA, Khodr HM. Optimal scheduling of a renewable micro-grid in an isolated load area using mixed-integer linear programming. Renew Energy 2010;35:151–6.
[13] Lilienthal P. How to Classify Microgrids: Setting the Stage for a Distributed Generation Energy Future; 2013.
[14] Rajaković N, Babić I, Batas Bjelić I. Development of distributed generation in Serbia caused by price of electricity – in Serbian language. CIGRE Zlatibor 2013.
[15] Tešić M, Kiss F, Zavargo Z. Renewable energy policy in the Republic of Serbia. Renew Sustain Energy Rev 2011;15:752–8.
[16] MERZ. The Energy Law. 124/12: Official Gazette of the Republic of Serbia; 2011.
[17] Batas Bjelic I, Rajakovic N. An overview of Serbian energy strategy development path 2015 with comparison of German and U.S. renewable energy policies – in Serban language. In: Proceedings of the second regional conference industrial energy and environmental protection, Zlatibor; 2010. pp. 1–8.
[18] MERZ. The Energy Sector Development Strategy of the Republic of Serbia by 2015; 2005.
[19] MERZ. Draft National Renewable Energy Action Plan. Belgrade: Ministry of Energy; 2012 (Development and Environmental Protection of Republic of Serbia).
[20] Covenant of Mayors. Available from: 〈http://www.covenantofmayors.eu/index_en.html, accessed 20/5/2014〉.
[21] Climate Alliance. Available from: 〈http://www.klimabuendnis.org/, acessed: 20/05/2014〉.
[22] Božović Danijela MA, Vladimir Pavlović M, Mirko Popović. Održivo energetsko upravljanje na lokalnom nivou: preporuke za unapređenje energetskog planiranja u Novom Sadu, Kragujevcu i Aranđelovcu – In Serbian language. Beograd: Beogradska otvorena škola; 2012.
[23] How to develop a sustainable energy action plan. Available from: 〈http://covenant.energy-cities.eu/IMG/pdf/seap_guidelines_en-2.pdf acessed: 20/05/2014〉. Covenant of mayors.
[24] Christoforidis GC, Chatzisavvas KC, Lazarou S, Parisses C. Covenant of mayors initiative—public perception issues and barriers in Greece. Energy Policy 2013;60:643–55.
[25] Raspoloživa sredstva i lična potrošnja domaćinstava u Republici Srbiji, prvi kvartal. Beograd (Milana Rakića 5): Republički zavod za statistiku Srbije, 1990–2013; 2013.
[26] Hiremath RB, Shikha S, Ravindranath NH. Decentralized energy planning; modeling and application—a review. Renew Sustain Energy Rev 2007;11: 729–52.
[27] Hakala E, Batas Bjelic I. Sustainable energy production in Serbia – leapfrogging or lagging behind? CBEES 2014, An interdisciplinary workshop on energy and society for emerging scholars. 〈 http://webappo.web.sh.se/p3/ext/custom.nsf/calendar?openagent&key=24_04_large_scale_energy_projects_a_view_from_society_1395837783932 〉.
[28] Tenenbaum B, Greacen C, Siyambalapitiya T, James K. From the bottom up: how small power producers and mini-grids can deliver electrification and renewable energy in Africa. Directions in Development. Washington, DC: World Bank; 2014 . http://dx.doi.org/10.1596/978-1-4648-0093-1. License: Creative Commons Attribution CC BY 3.0.
[29] Vodič za izvore finansiranja energetske efikasnosti i obnovljivih izvora – in Serbian lanugage, Centralno-evropski forum za razvoj CEDEF. Available from: 〈http://www.cedeforum.org/fajlovi/CEDEF%20Vodic%20za%20izvore%20finansiranja%20energetske%20efikasnosti%20i%20obnovljivih%20izvora%20energije.pdf〉; 2011 [accessed 20.05.14].
[30] Clercq GD. Analysis: renewables turn utilities into dinosaurs of the energy world. Paris: Reuters: Reuters; 2013.
[31] Mitra P, Selowsky M, Zalduendo J. Turmoil at twenty: recession. Recovery, and reform in central and Eastern Europe and the former soviet union. Washington DC: World Bank; 2010.
[32] Ashok S. Optimised model for community-based hybrid energy system. Renew Energy 2007;32:1155–64.
[33] Cormio C, Dicorato M, Minoia A, Trovato M. A regional energy planning methodology including renewable energy sources and environmental constraints. Renew Sustain Energy Rev 2003;7:99–130.
[34] Barnes DF, Floor WM. Rural energy in developing countries: a challenge for economic development. Annu Rev Energy Environ 1996;21:497.
[35] Wene C-O, Rydén B. A comprehensive energy model in the municipal energy planning process. Eur J Oper Res 1988;33:212–22.
[36] Kostevšek A, Cizelj L, Petek J, Pivec A. A novel concept for a renewable network within municipal energy systems. Renew Energy 2013;60:79–87.
[37] Protic SM, Batas Bjelic I. Rural electrification, legalislation and its impact on minorities: case study Serbia. In: Proceedings of the 13 symposium energieinnovation. Verlag der Technicher Universität Graz, Graz/Austria; 2014. pp. 275–276.
[38] Batas Bjelić I., Šošić D., Rajaković N. Energy loss in distribution network related to placement of solar photovoltaic systems. In: Proceedings of the second international conference on renewable electrical power sources, Belgrade; 2013. p. 47.
[39] Rojas-Zerpa JC, Yusta JM. Methodologies, technologies and applications for electric supply planning in rural remote areas. Energy Sustain Dev 2014;20: 66–76.
[40] Han Y, Young P, Zimmerle D. Microgrid generation units optimum dispatch for fuel consumption minimization. J Ambient Intell Humaniz Comput 2012;4: 685–701.
[41] Branker K, Pathak M, Pearce J. Review of solar photovoltaic levelized cost of electricity. Renew Sustain Energy Rev 2011;15:4470–82.
[42] Joskow PL. Comparing the costs of intermittent and dispatchable electricity generating technologies. Am Econ Rev 2011;101:238–41.
[43] Lambert T, Gilman P, Lilienthal P. Micropower system modeling with HOMER. Integration of alternative sources of energy. 2006; 379–418.
[44] Sinha S, Chandel SS. Review of software tools for hybrid renewable energy systems. Renew Sustain Energy Rev 2014;32:192–205.
[45] Katsigiannis YA, Georgilakis PS, Karapidakis ES. Genetic algorithm solution to optimal sizing problem of small autonomous hybrid power systems. Artificial intelligence: theories, models and applications. Berlin, Heidelberg: Springer; 2010; 327–32.
[46] Batas Bjelić I, Rajaković N, Ćosić B, Duić N. Increasing wind power penetration into the existing Serbian energy system. Energy 2013;57:30–7.
[47] Bronski P, Creyts J, Guccione L, Madrazo M, Mandel J, Rader B, et al. The economics of grid defection 2014, http://www.rmi.org/electricity_grid_defection.
[48] Weis TM, Ilinca A. The utility of energy storage to improve the economics of wind–diesel power plants in Canada. Renew Energy 2008;33:1544–57.
[49] Giannoulis ED, Haralambopoulos DA. Distributed generation in an isolated grid: methodology of case study for Lesvos – Greece. Appl Energy 2011;88:2530–40.
[50] Gokcol C, Dursun B. A comprehensive economical and environmental analysis of the renewable power generating systems for Kırklareli University, Turkey. Energy Build 2013;64:249–57.
[51] Al-Karaghouli A, Kazmerski LL. Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software. Sol Energy 2010;84:710–4.
[52] Fadaeenejad M, Radzi MAM, AbKadir MZA, Hizam H. Assessment of hybrid renewable power sources for rural electrification in Malaysia. Renew Sustain Energy Rev 2014;30:299–305.
[53] Lambert T, Gilman P, Lilienthal P. Micropower system modeling with homer. Integration of alternative sources of energy. Hoboken, New Jersey: John Wiley & Sons, Inc.; 2006; 379–418.
[54] Škokljev IA. Planiranje elektroenergetskih sistema: problemi, pitanja i odgovori iz odabranih oblasti. Belgrade: Taurus Publik; 2000 (in Serbian language).
[55] ENTSO-E. European network of transmission system operators for electricity. Available from: 〈https://www.entsoe.eu/resources/data-portal/country-packages/ acessed: 20/05/2014〉.
[56] NASA surface meteorology and solar energy; 2004.
[57] Pavlović TM, Milosavljević DD, Pirsl DS. Simulation of PV systems electricity generation using homer software in specific locations in Serbia. Thermal Sci 2013:333–47.
[58] EPS. Technical report for the year 2009, Available from: 〈http://www.eps.rs/Eng/Tehnicki%20Izvestaji/EPS_Tehncki_Godisnjak2009_en_web.pdf〉; 2009 [accessed 20.05.14].
[59] Rajaković N, Batas Bjelić I. Optimalno kombinovano sagorevanje biomase i komunalnog otpada u postojećim termoelektranama u Srbiji – in Serbian language. Energetika 2012:13–8 (Zlatibor 2012).
[60] Rajaković N, Batas Bjelić I. Smanjenje emisija CO_2 u sektoru zgradarstva Republike Srbije – in Serbian language. ZIBL 2012.